Multi-sensor observations of atmospheric transient signals associated with large earthquakes

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[**Subject/statement of problem**]To determine if there are measurable atmospheric signals preceding large earthquakes. The most recent catastrophic earthquakes (2004 Sumatra, 2008 China, 2011 Japan, and 2015 Nepal) claimed thousands of lives and caused extensive economic losses. Five years after the 2011 Tohoku, Japan Great Earthquake (M9.0)), the international science community is still seeking solutions for the early detection of major seismic events that wouldin order to minimize the loss of life. Multiple observations of earthquake precursory signals have previously been reported.The rRecent analyses of data from multi-instrument space-borne and ground observationshave providedsevidences forthe existence of pre-earthquake atmospherics signals.(Hayakawa,2012,; Tramutoli et al., 2015). These are some As This isonly an initial efforts.Full implementation will requiresince this is a global search and, therefore, willrequiring requireglobal satellite monitoring.

[**Background**]The search for pre-seismic signals has been conducted for many years (e.g., Martinelli, 1998). Multiple observations of earthquake precursory signals have previously been reported. Recent analyses of data from multi-instrument space-borne and ground observations have provided evidence for the existence of pre-earthquake atmospheric signals (Hayakawa, 2012; Tramutoli et al., 2015). WIn this current study, we are currently investigating the link between satellite-recorded abnormal atmospheric signals prior to large earthquakes. These studies would have an impact on our understanding of the physics of earthquakes and the phenomena that precedes their energy release. The recent advances in earth observing space technology have helped to advance the scientific understanding of the nature of pre-earthquake phenomena in the atmosphere

[**Objective(s)**].We are searching for pre-seismic observations, which might give warning of a major earthquake. Our investigation is based on a possible connection between satellite observations of anomalous atmospheric thermal transient signals prior to major earthquakes. The latest NPOESS (National Polar-orbiting Operational Environmental Satellite System) and NASA EOS (Earth Observing Systematellite) have space-borne sensors that provide a unique opportunity for observing making observations that could determine if there is a relationship between a lithosphere-atmosphere interaction which might lead to an earthquake hazard reduction.

[**Previous work**]InitiallycomparingsSatellite thermal infrared (TIR) imagery recorded by AVHRR (Gorny et al., (1988); Tronin et al., (2002;) and,Dey et al., .(2004)) havehas been used to develop a simple approach of analysis, that is, comparing before and after images over the epicenter of the

earthquake. ~~With u~~Utilizing both polar orbiting and geosynchronous satellite observations, new techniques have been proposed to use sub-pixel level co-registration and geo-referenced imagery data from GOES, Meteosat, AVHRR, ~~.~~and Landsat (Bryant et al., 2003; Di Bello et al., 2004). One of the main problems in detecting TIR anomalous signals is defining abnormal and normal TIR fluctuations. To address this problem, we developed a new approach using a time series of TIR data over earthquake prone regions, and based on pixel thermal radiation variance from previous established base lines that would ~~identify~~allow identification of anomalous TIR signals (Tramutoli et al., 2001, Filizzola et al., 2004, Cervone et al., 2006, Ouzounov et al, 2007). After the launch of the EOS satellites (1999-Terra and 2002-Aqua), a new approach, based on a multi-spectral IR component,has been tested, based on Land Surface Temperature (LST) ~~for~~ derived from the 11-micron data (Ouzounov and Freund, 2004). ~~Latest~~The latest observations with NPOESS and AIRS of atmospheric environmental parameters revealed an increase in radiation and a transitional change in Outgoing Longwave Radiation (OLR) in the 8-12 micron~~s~~ range (Ouzounov et al., 2007). OLR transitional changes recorded at the TOA (top of the atmosphere) over seismically active regions were proposed to be related to thermodynamic processes within the earth's crust that processed the earthquakes (Ouzounov et al., 2011; Pulinets and Ouzounov, 2011).

[Methods]In our studies, we use OLR data from the NASA satellite EOS Aqua/AIRS. ~~these~~ The Aq~~g~~ua/AIRS~~irs~~ data were provided by GES DAAC, and OLR measurements from NCEP/NOAA were obtained from NOAA. A daily mean global data base, with a spatial resolution of 1° by 1°, was used to study the OLR activity and variability in the region of four recent major earthquakes (Table 1).

~~-~~OLR was calculated at the TOA and has been used to study the Earths radiation budget since it represents emissions from the Earth's surface, lower atmosphere and clouds, and is sensitive to near surface and cloud temperatures. Daily mean OLR values were calculated from these raw data using separate algorithms for each satellite. Observations from NOAA HIRS/OLR are based on the long wave flux estimation of Ellingson et al. (1989) and for the NASA Aqua/AIRS OLR on the multi-spectral long wave estimates from Mehta and Susskind (1999) and Susskind and Blaisdell (2008).

~~-~~The transitional OLR anomalous data usually varied between 15-19 W/m^{2} they were a residual derived from the daily mean OLR and compared with the background field, defined by multiple years of observations over the same location, local time and normalized by the standard deviation (Ouzounov et al, 2007;~~,~~ 2011). We studied the daily variability of OLR in relation to the latest major earthquakes ~~–~~M6.0 of Aug 24, 2014 in Napa, CA and M7.7 and 7.3 of April 24 and May12, 2014 in Nepal (Table 1). From August 2nd to 4th preceding the Napa earthquake a large anomalous OLR transient field at the TOA over Northern California was detected. This anomalous signal was shifted ~~in~~ to the northeast and was the largest OLR transition anomaly over the US at this time (Ouzounov et al, 2014). The 2015 Nepal earthquake results show that in mid March 2015, a rapid ~~augment~~ increase~~?~~ of transient infrared radiation was observed from the satellite data,~~and~~ with an anomaly near the epicenter that reached a maximum on April 21-22, three days before the M7.8 (Figs. 1 and 2). A continued analysis revealed another OLR transient anomaly on May 3-4 (8 days in advance), which was apparently associated with the M7.3 earthquake of May 12, 2015~~.~~ (Ouzounov et al., 2015).

[Results]Our results show that processes related to infrared signals were observed by both NOAA/AVHRR and Aqua/AIRS satellite observations near the epicentral area several days before the earthquakes ~~.~~(Figs.1 and 2). The OLR hot spot appeared~~s~~ quickly, stayed~~s~~ over the same region for

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several hours, and then disappeareds rapidly. The time lag for the M6.0 earthquake in California ~~is~~ was 20 days;~~,~~ for the Nepal event, the time lag was 2-8 days. This enhancement of OLR could be explained as a result of water vapor condensation on ions, with ~~the~~a large amount of latent heat being released. The initial process involves an ionization of the near-ground layer from the increased concentration of gasses (including radon) emitted from active tectonic faults (Pulinets and Ouzounov, 2011). The transient nature in radiative emission preceding large earthquakes follows a general temporal-spatial evolution pattern, which has been seen in other large earthquakes worldwide (Kuo, 2011 and Ouzounov et al., 2016).

[**Conclusion(s)**] From space-born recording of atmospheric conditions, we have shown the consistent occurrence~~presence~~ of radiative emission (OLR) anomalies at the TOA,~~occurring consistently~~ over the region of maximum stress~~,~~ and preceding large earthquakes. Due to their long duration, these anomalies do not appear to be of a meteorological origin. This analysis of atmospheric parameters for most recent major earthquake demonstrated the presence of correlated variations of transient OLR anomalies in the atmosphere, implying their connection with the earthquake preparation processes and suggesting the existence of an ~~atmosphere~~ atmospheric response triggered by the coupling processes between lithosphere and atmosphere.

Tabel 1. List of ~~the~~earthquakes (USGS) studied. [Text mentioned four earthquakes (?).]

	Name	Date (mm/dd/yyyy)	Geographic lat/lon (°)	Time (UTC)	M	*H* (km)
1	Napa V~~v~~alley, California, US	08/24/2014	38.21 N/122.31 W	10:24:44	6.0	11.11
2	Gorkha, Nepal	04/24/2015	28.23 N/84.73 E	06:11:25	7.8	8.2
3	Kodari, Nepal	05/12/2015	27.80 N/86.06 E	07:05:19	7.3	15.0

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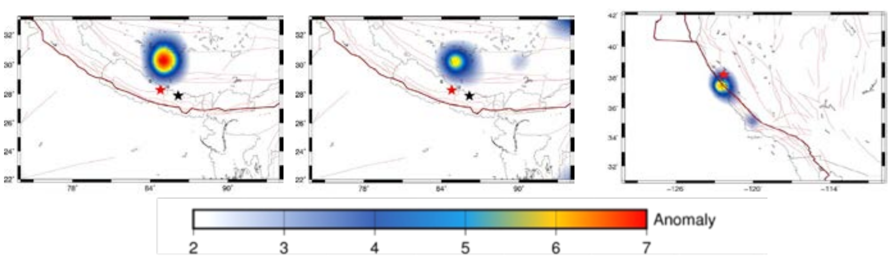

Figure 1. Pre-~~e~~Earthquake satellite maps of OLR observed a few days before the earthquakes listed~~shown~~ in Table 1.~~:~~ (Left ~~A~~)~~:~~ Nepal,~~–~~ April 21-22, 2015 ~~(-2 days)~~, 06 .00 UTC (-2 days); (Middle~~B~~) ~~–~~Nepal,~~–~~ May 3-4, 2015, 00 UTC (-8 days); (Right~~3C~~)~~.~~ California,~~–~~ August 1-3, 2014, 00 UTC (-21 days).

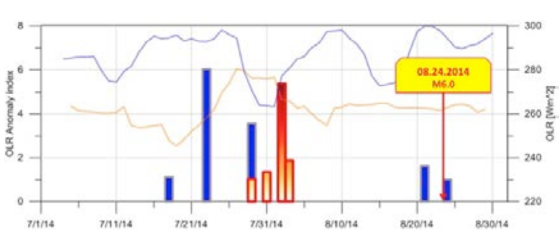

Figure 2. Time series of daily nighttime anomalous OLR for two~~2~~ months over the epicentral regions

(box 1°x1°) observed from NOAA/AVHRR (red) and AQU~~I~~A/AIRS (blue) for the three earthquakes listed ~~shown~~ in Table 1.

~~; A): Nepal M7.7 of April 24 and M7.1 of May 12, 2015; B).M6.0 of Aug 24, 2014 California, US~~

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